SPE
Society of Petroleum Engineers

SPE 21866

Slant-Hole Completion Test in the Piceance Basin, Colorado

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ABSTRACT

The Piceance Basin of western Colorado contains a major gas resource in the tight naturally fractured sandstones, siltstones and coals in the Mesaverde. The objective of the Slant Hole Completion Test, funded by the U.S. Department of Energy, is to evaluate directional and horizontal drilling as an alternate development strategy for these reservoirs.

The well is located 700 ft south of the DOE Multiwell Experiment site in Section 34, T6S, R94W, Garfield County, Colorado. The hole was designed to intersect the paludal Mesaverde at 60° beneath the Multiwell pad and continue north to intersect the Cozzette close to 90°. The well is positioned to drill normal to the regional fracture system. Coring operations included a coal pressure core, 276 ft of conventional core across two paludal sandstones, and 118 ft of conventional core perpendicular to the natural fracture system in the Cozzette.

Drilling operations proceeded as planned through the first build interval, pressure coring, and conventional coring in the 60° hole. Subsequent caving in the coal and in the adjacent naturally fractured siltstone, in conjunction with lost circulation in the Rollins, necessitated prematurely running 7-in. casing below the Rollins. The remaining 800 ft of hole drilled was 6-in. diameter, cased with 4-1/2-in. liner. The high hole angle, in conjunction with the long tangent (60°) section (1,824 ft), made sliding the 4-3/4-in. motors in the second build extremely difficult. Drillpipe conveyed logging operations were successfully conducted in the Cozzette.

INTRODUCTION

The surface location for the Slant Hole Completion Test is 700 ft south of the DOE Multiwell Experiment site in Section 34, T6S, R94W, approximately 7.5 miles west of Rifle, in Garfield County, Colorado. The hole was designed to intersect two paludal Mesaverde sands and bounding coals at approximately 60° beneath the Multiwell pad and to proceed north to intersect the Cozzette at 88° and drill parallel to bedding for a distance of 500 ft. The well was positioned to drill normal to the regional fracture trends identified in previous studies undertaken at the Multiwell Experiment. The slant hole was spudded April 10, 1990, and reached 9,466 ft TMD in the Cozzette on August 4, 1990.

The first completion target encountered was the paludal Mesaverde 3 and 4 sandstones and their bounding coals encountered between 7,366 and 7,581 ft. Figure 1 shows the vertical Multiwell logs across the paludal and Cozzette target reservoirs. The paludal 3 sand is a 26-ft thick channel sandstone and the paludal 4 sand is a 19-ft thick splay sandstone. The coal immediately above the paludal 4 sand is 7 ft thick while the two thin coals at the base of the paludal 3 sand together are approximately 5 ft thick. The measured thickness of these zones is about twice the vertical thickness since the hole angle through the paludal interval is approximately 59.3°. Previous studies indicate these sandstone reservoirs have poor lateral continuity over a distance of several hundred feet. The coals, however, have a much greater lateral extent and can be correlated between wells.

The second completion target was the Cozzette sandstone encountered at a depth of 7,910 ft TVD or 8,860 ft MD. The target interval was in the upper bench of the Cozzette, encountered at a depth of 7,938 ft TVD or 8,970 ft, which locally, is approximately 64 ft thick. At the Multiwell site, the upper 24 ft of this interval contains pyro-bitumen with resulting poor reservoir quality. Consequently, the second build for the slant hole was positioned to achieve the maximum hole angle approximately 32 to 34 ft vertically into the upper Cozzette. A maximum hole angle of 85.1° was achieved at a depth of 7,939 ft TVD or 8,990 ft,

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approximately 30 ft into the upper Cozzette. The hole was then drilled 410 ft laterally in the 40-ft vertical thick upper Cozzette target. The hole was subsequently drilled a total depth of 7,990 ft TVD or 9,466 ft TMD, 66 ft into the underlying siltstone.

WELL DESIGN

A 17-1/2-in. hole was drilled with a small service unit to 115 ft and 13-3/8-in., 54.5 lb/ft, K55 casing was run to total depth and cemented to surface with 470 sacks of cement.

The drilling rig was moved in and a 12-1/4-in. hole was drilled through the Wasatch and 200 ft into the Mesaverde to a depth of 4,130 ft. A 9-5/8-in., 36 lb/ft, K55 casing string was run to 4,130 ft and cemented back to surface with 835 sacks of cement to isolate major caving and lost circulation zones in the Wasatch.

An 8-3/4-in. hole was then drilled to the first kickoff point at 6,365 ft. Hole angle was built in the 8-3/4-in. hole using a 6-3/4-in. diameter angle-build motor having a design build rate of 8.7°/100 ft. The hole angle was built from 0° at 6,365 ft to 55.2° at 7,010 ft for an effective build rate of 8.6°/100 ft. Conventional rotary coring operations were undertaken in the paludal Mesaverde between 7,324 and 7,581 ft. A pressure core, co-funded by the Gas Research Institute, was undertaken in a coal between 7,371 and 7,380 ft to directly determine the methane content and compare it with conventional coal coring and desorption in the same interval. Drilling then proceeded in the tangent interval using both steerable motors and conventional rotary methods to 8,667 ft and a hole inclination of 59.1°, in the Mancos shale, below the base of the Rollins sand. Subsequent caving in the overpressured coals and siltstones between 7,350 and 7,400 ft, and lost circulation in the Rollins at 8,200 ft necessitated running the 7-in. casing early to isolate these intervals. The 7-in., 29 lb/ft N80 casing was run to 8,489 ft, where it became stuck, and was cemented in place with 770 sacks cement. At this time, the 5-in. drillpipe and handling equipment was changed out to 3-1/2-in. equipment.

A 6-in. hole was then rotary drilled to the second kickoff point at 8,834 ft. The second build was drilled from 8,834 to 8,949 ft with 4-3/4-in. diameter, 19.4°/100 ft angle-build motors. Inclination was built from 62.5° to 81.5° for an effective build rate of 15.3°/100 ft. The last 40 ft of the second build to 8,990 ft, was drilled with a conventional rotary angle-build assembly and built the hole angle to 83.4°. The conventional rotary angle-build assembly was used to build hole angle due to the extreme difficulty experienced sliding the 4-3/4-in. angle-build motors in the high angle, second build interval. At the end of the second build, the wellbore azimuth was due north, with the Cozzette dipping 1.7° to the north. The effective hole angle in the Cozzette at the end of the second build was 85.1° at 8,990 ft. The well was conventionally rotary cored from 8,990 to 9,108 ft. The hole was then rotary drilled to 9,466 ft TMD, and the open-hole section was successfully logged using drillpipe conveyed logging techniques. A 4-1/2-in., 13.5 lb/ft, N80 liner was run to 9,466 ft (top liner tieback at 8,200 ft) and cemented with 300 sacks of cement. Mechanical problems that developed following liner cementing operations resulted in a major washover operation. Figure 2 illustrates the wellbore configuration while Figures 3 and 4 present the wellbore profile and plan views. The casing program is shown on Table 1.

DRILLING EQUIPMENT

Drilling Rig

The drilling rig chosen to drill the slant hole had a depth capacity of 11,500 ft with 5-in. drillpipe. This diesel electric rig was equipped with a 131-ft mast having a 357,000 lb hook-load capacity using 10 lines. The rig was equipped with an 18-ft substructure and had a 300,000 lb set back capacity to efficiently rack 7,500 ft of 5-in., 19.50 lb/ft drillpipe and 2,100 ft of 5 in, 50 lb/ft heavy weight drillpipe.

Drillpipe and Heavy Weight

The 5-in., 19.50 lb/ft, Grade 'E' drillpipe with a 4-1/2-in. IF tool joint was chosen as the lightest pipe that could be used in the 60° slant hole without buckling under the expected 30,000 to 40,000 lb bit weight. The 5-in. heavy weight drillpipe was selected for handling the reverse bending stresses induced by rotating the pipe in the build intervals. For the maximum expected curvature rate of 10°/100 ft, the reverse bending stress was predicted to be 60 percent of the expected fatigue endurance limit for the 5-in. heavy weight drillpipe. The 5-in. drillpipe and 5-in. heavy weight drillpipe was changed out for 3-1/2-in., 15.50 lb/ft, S135 drillpipe and 3-1/2-in. 25.3 lb/ft heavy weight drillpipe once the 7-in. casing was run and cemented at 8,489 ft. The physical properties of the 3-1/2-in. S135 drillpipe and 3-1/2-in. IF tool joint was sufficient to handle the buckling and reverse bending stresses imposed during rotary drilling operations in the second build and in the Cozzette 85° hole.

Mud Pumps

The rig was equipped with three 750 HP mud pumps. The circulation rate required by the mud motors to drill an 8-3/4-in. hole through the first and second build, and the tangent interval called for 400 gpm at 3,000 psi. Two of the pumps running at about 100 SPM could supply the required circulation rate. The third pump was held in reserve as a spare. During the drilling of the 6-in. diameter hole below 8,667 ft, the required circulation rate of 165 gpm at 3,000 psi was supplied by one pump.

Mud System

A low solids non-dispersed (LSND) mud system was chosen to drill the Mesaverde sandstone, siltstone, shale and coal sequence. This highly shear thinning system was chosen because it has a minimum of solids for improved penetration rate along with minimum viscosity at the bit, and provided for maximum annular velocity for hole cleaning. This LSND mud system had the following properties:

(1) pH at 9.0 to 9.5;

(2) 30 minute filtrates at 5 cc to 6 cc;

(3) mud weights maintained with barite to 16.6 ppg; and

(4) 8 percent diesel and a non-hydrocarbon lubricant used to increase lubricity.

The rig was equipped with a fine screen shale shaker, desander, desilter, mud degasser, and a gas buster. This mud system was chosen over an oil base mud due to the excellent results with a LSND mud at MWX-3 and for environmental reasons.

DIRECTIONAL DRILLING

First Build

An 8-3/4-in. diameter hole was drilled out from under the 9-5/8-in., 36 lb/ft intermediate casing at 4,130 ft to the first kickoff point at 6,365 ft. A gyroscopic survey run at 6,365 ft indicated the hole angle to be 0.57° and determined the bottom hole location to be 65.83 ft east and 26.30 ft north of the surface location on an azimuth of N68°E. The eastward drift of the hole is attributable to intersecting and tracking a minor fault scarp initially encountered at 2,622 ft.

The entire first build interval was drilled with one 8.7°/100 ft angle-build motor assembly. The first build interval was completed at 7,010 ft with an inclination of 55.2° on an azimuth of N4.3°W for an effective build rate of 8.6°/100 ft.

An 8-3/4-in. IADC Code T646 mosaic bit was used to initiate the build and drilled from 6,365 to 6,423 ft, but was pulled, severely worn, when penetration rates did not exceed 3.9 ft/hr. One 8-3/4-in., IADC Code 537, bit with heel buttons and stabilizer lugs drilled the remainder of the first build interval to 7,010 ft at an average penetration rate of 10.3 ft/hr.

Tangent

8-3/4-in. Tangent Section to 8,667 ft. The first tangent section was started with a steerable motor assembly. This assembly drilled 295 ft to the first core point at 7,305 ft while increasing the hole angle to 59.3°. An IADC Code 537 bit with heel buttons and stabilizer lugs drilled this interval at an average penetration rate of 8.1 ft/hr. At this point, a wiper run was made with an 8-3/4-in. hole opener prior to initiating coring operations.

After completion of coring operations at 7,581 ft, drilling the 8-3/4-in. hole in the tangent section resumed with the 8-3/4-in. hole being drilled to 8,667 ft. Nine bottom hole assemblies were employed in this interval including both rotary and steerable DTU motor assemblies. Nine bits, one re-run IADC Code T646 mosaic bit and eight IADC Code 537 bits with heel buttons and stabilizer lugs, were used to drill this interval. Penetration rates for the various bits ranged from 3.2 ft/hr to 7.7 ft/hr and averaged about 4.8 ft/hr. The mosaic bit averaged 3.6 ft/hr for 86 ft, prior to being pulled. The eight IADC Code 537 bits averaged 5.0 ft/hr over a distance of 995 ft.

Fishing Operations. Two separate fishing operations occurred while drilling in the tangent section. The first at 7,829 ft resulted from losing two cones from an IADC Code 537 bit while drilling with a steerable DTU motor and MWD to raise hole angle. The second fishing operation occurred at 8,270 ft with the loss of one cone, two nose cones and bearings from a second IADC Code 537 bit, again while running a steerable DTU motor and MWD.

Hole Caving and Lost Circulation. Lost circulation into the Rollins sandstone, topped at 8,199 ft caused the drillpipe to become differentially stuck while drilling at 8,270 ft. The overpressured coals and fractured siltstones above the Rollins then kicked, unloading gas into the wellbore and causing the hole to cave. The drillpipe was worked loose and the Rollins was successfully treated with "Flo-Chek" to mitigate lost circulation. Drilling operations in the tangent continued with frequent tight spots to 8,667 ft. On a short trip to clean the hole, the drillpipe became stuck at 7,414 ft. Circulation with full returns was maintained even though the drillpipe could not be rotated or reciprocated. The drillpipe was backed off in the tangent section at 7,196 ft. A fishing assembly consisting of a cut lip screw-in sub, bumper jars, and oil jars was run to the top of the fish and screwed into the fish. Following 1-1/2 hours jarring and circulating, the fish came free. Large, angular pieces of coal and siltstone were then circulated from the well while conditioning the hole. With the frequency of hole caving in the paludal coals and occurrence of stuck drillpipe steadily increasing, it was decided to run and cement the 7-in. casing at 8,667 ft. Due to the threat of further caving, no open hole logs were run in the 8-3/4-in. wellbore.

7-in. Casing Set Through the Rollins. One hundred ninety-eight (198) joints of 7-in., 29 lb/ft, N80 LT&C casing were run in the hole to 8,489 ft, 290 ft below the Rollins and into the Mancos shale. One hundred twelve (112) centralizers were placed on 20-ft centers through the tangent and build sections of the hole. Difficulty was experienced running the casing between 7,287 and 8,489 ft. The casing was worked and washed down through this interval. Full returns were experienced while washing the casing down to 8,489 ft. The casing became stuck completely at that point, 178 ft off bottom. The casing was then cemented in one stage with 340 sacks of premium cement containing light weight additives and retarder followed by 430 sacks of premium cement containing silica flour and retarder, plus additives to control cement weight and water loss. Full returns were experienced throughout the job. A cement bond log run 5 days after completion of cementing operations indicated the cement top at 6,405 ft, approximately 40 ft below the top of the first build and 2,900 ft below the calculated cement top at 3,500 ft.

6-in. Tangent Section to 8,834 ft. The 5-in., 19.50 lb/ft drillpipe, 5-in., 50 lb/ft heavy weight drillpipe, and the associated handling equipment was replaced with 3-1/2-in., 15.50 lb/ft, S135 drillpipe and 3-1/2-in., 25 lb/ft heavy weight drillpipe and handling equipment prior to drilling out from under the 7-in. casing. The shoe joint, 178 ft of 8-3/4-in. open hole, and 16 ft of new hole were drilled out with a conventional rotary drilling assembly to a depth of 8,683 ft. An IADC Code M645 PDC bit was then run on a rotary angle-hold assembly and drilled to the second kickoff point at 8,834 ft, a distance of 151 ft, at an average penetration rate of 9.7 ft/hr.

Second Build

The second kickoff point was determined using detailed structural mapping in conjunction with well-to-well correlation to stratigraphic markers, as the well was being drilled. These stratigraphic markers, illustrated on Figure 5, include the major paludal coals, Rollins sandstone, Mancos Tongue, a thin geologic marker 84 ft into the Mancos Tongue characterized by a high gamma ray and a high neutron porosity, and the top of the upper Cozzette interval. A gamma ray log was run through drillpipe to fine tune this correlation prior to reaching the second kickoff point. This was combined with MWD survey information to successfully project the expected depths of the markers. This procedure resulted in an accurate determination of the second kickoff point at 8,834 ft.

The 6-in. diameter hole in the second build interval was drilled with 19.4°/100 ft angle-build motors using three IADC Code M645 PDC bits and three IADC Code D2X5 natural diamond bits. Nine fixed angle-build assemblies were run between 8,834 and 8,949 ft.

The penetration rates were very low in the second build interval due to difficulty in sliding the 4-3/4-in. fixed angle-build motor and the 4-3/4-in. MWD in the high angle hole. At 8,949 ft it became impossible to further slide the 4-3/4-in. angle-build motor and MWD. The penetration rates through this interval ranged from 0.3 ft/hr to 4.3 ft/hr while using the fixed angle-build motor assembly, and averaged slightly less than 1.0 ft/hr. At this time it was decided to run a rotating angle-build assembly to increase penetration rate and complete drilling the second build. A rotating angle-build assembly was run at 8,949 ft and drilled to the end of the second build in the upper Cozzette at 8,990 ft. Inclination was built from 62.5° at 8,834 ft to 83.4° at 8,990 ft for an effective build rate of 13.4°/100 ft.

Horizontal Section

Detailed structural mapping has determined that the Cozzette sandstone dips to the north at 1.7° in the area immediate to the Slant Hole Completion Test. Further, the wellbore azimuth at the top of the 40-ft (vertical thickness) upper Cozzette target interval is essentially due north. Consequently, the effective angle of penetration of the upper Cozzette is 85.1°.

After completing coring operation in the upper Cozzette between 8,990 and 9,108 ft, a rotary angle-building assembly was run in the hole with an IADC Code D2X5 natural diamond bit. The entire horizontal section of the hole was drilled using surface rotation. Numerous natural fractures were encountered drilling from 9,108 to 9,398 ft, the base of the upper Cozzette interval. Progressive penetration of fractures was indicated by loss of 16.6 ppg drilling fluid and, recurring, sporadic increases of gas on the chromatograph while drilling. The hole was bottomed at 9,466 ft, approximately 68 ft into the siltstone below the base of the upper Cozzette.

Drilling the 476 ft of 85.1° lateral between 8,990 and 9,466 ft in the upper Cozzette required one IADC Code D2X5 and one D5X5 natural diamond bit. The penetration rates varied from 4.8 ft/hr to 5.7 ft/hr and averaged slightly less than 5.5 ft/hr.

CORING OPERATIONS

Pressure Core in Paludal Coal

The objective of the pressure core of a paludal coal seam, cooperatively funded by the Gas Research Institute as an add-on activity, was to accurately measure the original gas content and coal mechanical properties. Based on geologic projections, two 10-ft pressure cores were cut in siltstone and coal stringers between 7,305 and 7,324 ft, some 30 ft (vertically) above where the coal was ultimately encountered. Following a reaming run to open the hole from 6-1/2 to 8-3/4 in., 47 ft of conventional core was then cut (in three runs) and the 10-ft coal seam at the top of the paludal 4 sand was finally located at 7,366 ft. Five feet of coal was cut with the conventional core barrel and was immediately loaded in canisters for low pressure gas desorption measurements. A successful pressure core was then taken in the 60° inclined wellbore from 7,371 to 7,380 ft with 9 ft of coal recovered and full pressure at the surface. Subsequent desorption of the pressure core indicated a methane content of 765 scf/ton, not corrected for ash content. Table 2 presents the results of coal desorption testing using samples from the conventional core and the pressure core.

Conventional Core in the Paludal Mesaverde

Conventional 4-in. diameter core was cut from 7,324 to 7,371 ft and from 7,380 to 7,581 ft in the 60° inclined wellbore. A 6-3/4-in. by 4-in. by 60-ft core barrel with a brass studded (centralized) inner barrel, and an 8-3/4-in. by 4-in. IADC Code M585 core bit was used to obtain core in the paludal interval.

The first two core runs, taken to locate the pressure core target coal, from 7,324 to 7,341 ft, and from 7,341 to 7,358 ft were prematurely terminated by core barrels jamming due to the highly fractured nature of the coal stringers, siltstones, and shales encountered. The third core from 7,358 to 7,371 ft was terminated 5 ft into the target coal to initiate pressure coring operations. The fourth conventional core taken from 7,380 to 7,418 ft encountered 5 natural fractures and was terminated when the core barrel jammed in a minor coal. The fifth core taken between 7,418 and 7,478 ft encountered 9 natural fractures in 39 ft of fine- to medium-grained sandstone. The sixth core taken from 7,478 to 7,538 ft encountered 24 fractures in 29 ft of fine-grained sandstone. A swarm of 21 of these fractures within a three foot interval were not mineralized and contained residual guar gels from a hydraulic fracture stimulation conducted in the paludal 3 sand in MWX-1 during 1984. The seventh core taken from 7,538 to 7,581 ft encountered 5 natural fractures in 24 ft of fine-grained sandstone, 10 ft of mudstone, and 7 ft of coal. The coal recovered between 7,571 and 7,579 ft was loaded into canisters for low pressure gas desorption. Core recovery included the coal above the paludal 4 sand, the paludal 3 and 4 sands, and the coal below the paludal 3 sand (Figure 6). Mud weight during coring operations was maintained at 13.3 ppg.

A total of 43 fractures were observed in the paludal Mesaverde core, of which 22 were mineralized and open, while a swarm of 21 non-mineralized fractures over a three foot interval represented the hydraulic stimulation of the paludal 3 sand in MWX-1. Figure 6 illustrates the location of the natural fractures encountered in the paludal cored interval. Table 2 presents the results of the low pressure desorption for the conventionally cored coals above the paludal 4 sand and below the paludal 3 sand.

Cozzette Core

Conventional 2-5/8-in. diameter core was cut from 8,990 to 9,108 ft in the 85.1° Cozzette lateral. A 4-3/4-in. by 2-5/8-in. by 30-ft conventional core barrel with brass wear pads at the midpoint position on the inner barrel for stabilization was used with a 6-in. by 2-5/8-in. IADC Code D6X5 core bit to cut 118 ft of Cozzette core.

The eighth core taken from 8,990 to 9,020 ft recovered 30 ft of sandstone containing 5 natural fractures. The ninth core taken from 9,020 to 9,050 ft recovered 30 ft of sandstone with 12 natural fractures. The tenth core taken from 9,050 to 9,080 ft recovered 26 ft of sandstone containing 11 natural fractures. The eleventh core taken from 9,080 to 9,108 ft recovered 26-1/2 ft of sandstone containing 7 natural fractures. Gas entry during coring operations caused the drilling fluid weight to drop from 16.6 ppg to 16.4 ppg while cutting the last core.

A total of thirty-five (35) mineralized, mostly open natural fractures were observed in 118 ft of core taken in the Cozzette. Figure 7 illustrates the location of the natural fractures encountered in the Cozzette cored interval.

MUD WEIGHT

Figure 8 presents a comparison of mud weight with true vertical depth between the three MWX wells and the slant hole. It is interesting to note that a 10 percent increase in mud weight was required to maintain control in the slant hole in intervals penetrated at 60° and above, over that required in the equivalent interval in the vertical MWX wells. The higher observed formation pressures are a result of intersecting open natural fractures, thus directly linking the wellbore with the reservoir.

TORQUE AND DRAG

Table 3 presents the observed torque and drag at four points along the hole profile. An 8-3/4-in. hole was drilled through the first build and most of the tangent section with 5-in., 19.50 lb/ft Grade G drillpipe with 2,100 ft of 5-in., 50 lb/ft heavy weight drillpipe in the first build. The increased coal caving in the tangent section between 7,350 and 7,400 ft caused torque to increase from an expected 10,700 ft-lbf to a maximum of 14,100 ft-lbf.

After 7-in. casing was set at 8,489 ft to isolate lost circulation and caving intervals, a 6-in. hole was ultimately drilled to 9,466 ft TMD using 3-1/2-in., 15.50 lb/ft drillpipe and 3-1/2-in., 25 lb/ft heavy weight drillpipe. A portion of the second build was rotary drilled from 8,908 to 8,923 ft to mitigate hole problems. Further, the entire Cozzette interval was rotary drilled and cored between 8,949 and 9,466 ft. The torque observed while rotary drilling was well within the endurance limits of the tubulars. The minimal torque results from the use of 8 percent diesel and a non-hydrocarbon lubricant in a well maintained low solids non-dispersed mud system.

DRILLPIPE CONVEYED LOGGING

The log suite for the Cozzette consisted of the Dual Induction Spherically Focused Log, the Lithodensity, Compensated Neutron, Gamma Ray, and Caliper. The open hole section was logged from 9,461 ft, below the upper Cozzette, to the 7-in. casing seat in the Mancos Tongue at 8,489 ft. The Compensated Neutron log was run through casing to the cement top at 6,405 ft. The logs were run in triple combination using drillpipe conveyed logging techniques. The side-door entry sub was attached after running 6,400 ft of 3-1/2-in. drillpipe. The logging operation went smoothly and log quality was good.

The operation required a careful coordination of drilling and logging crews since logging was performed while tripping drillpipe into and out of the hole. Tripping into the hole took approximately 14 hours and required some working of the drillpipe to get through the second build and to total depth at 9,466 ft. As well as providing logs on measured depth, the MWD survey was input to provide logs on true vertical depth for correlation with offset wells.

MECHANICAL PROBLEMS FOLLOWING LINER CEMENTING

Twenty-nine (29) joints of 4-1/2-in., 13.5 lb/ft, N80 LT&C liner were run on drillpipe to 9,466 ft. The top of the liner tieback sleeve was landed at 8,200 ft, and the liner was centralized at 20-ft intervals throughout its length. A liner packoff was not run in conjunction with the rest of the liner assembly, as originally planned, because (1) of the possibility of high pressure during cement displacement prematurely setting the hydraulic set liner packoff, and (2) had the plugs not landed properly, it would have been impossible to set the liner packoff. The liner was then cemented with 300 sacks of premium cement containing silica flour and a cement retarder, plus additives to control cement weight, water loss, and lost circulation. The cement slurry weight was 16.8 lb/gal.

Following 12 hours waiting on cement, a rerun 6-in. bit and a casing scraper were run in the well to 7,822 ft, approximately 400 ft above the liner tieback, to clean out the expected 200 to 300 ft of fill and polish the liner tieback sleeve prior to running an external liner packoff.

Circulation was established, and continued until heavy mud cut cement and practically straight unset cement was circulated from the hole. The drillpipe was worked until returns were too thick to pump.

Attempts to pull out of the hole, to reverse circulate down the casing-drillpipe annulus, and to pump straight water down the drillpipe to move the mud, all proved unsuccessful. Recovery operations with wash over pipe were initiated at 346 ft on August 9, 1990. Initially, washover operations recovered 300 to 400 ft of fish per day. Then, even though this part of the well is very straight and vertical, the fish began laying against one side of the casing. Pipe recovery became slower and slower, since every tool joint had to be milled with washover shoes. Finally, after recovering a total of 5,335 ft of fish, progress essentially stopped. At that point pipe recovery operations were halted due to budget considerations and the lack of progress. On September 5, 1990, when operations were stopped, 2,487 ft of fish remained to be recovered.

At this time, the U.S. Department of Energy is considering the option of cutting off and pulling the 7-in. casing at 5,300 ft, and then drilling a sidetrack targeting the original completion intervals, but up to 1,000 ft to the east of the old wellbore.

CONCLUSIONS

A number of significant findings on the production potential of tight sands and coals were made during the drilling of the slant hole through the Mesaverde Group in the Piceance Basin.

- Possibly the most significant finding is that the majority of natural fractures cored in the Cozzette are open slots in the formation at depth. These fractures form high permeability channels for gas flow from the tight reservoir to the wellbore. This unexpected finding was a surprise, since the few fractures cored in the MWX wells were completely mineral filled.

- The coal seams and tight gas sands penetrated by the slant hole in the paludal Mesaverde exhibit high gas production potential. This was evidenced by repeated heavy gas kicks and caving of coal particles into the wellbore. This behavior is due to the well's 60° intersection of the coal cleating system and the natural fracture network in the tight sands. Again, the same tight formations did not react with significant gas shows when drilled vertically at the Multiwell site.

- The 60° and horizontal sections of the slant hole required up to 10 percent higher mud weight to control gas influx at equivalent vertical depths than did the vertical holes at the Multiwell site. The higher observed formation pressures are a result of intersecting multiple natural fractures, thus directly linking the wellbore with the reservoir.

- The pressure core taken in the paludal Mesaverde coal indicated a gas content of 765 scf/ton. This is an extremely high gas content and shows that the paludal coals represent a significant gas resource in this part of the Piceance Basin. Gas contents in the 550 scf/ton range measured in two conventionally cored coals adjacent to the pressure cored interval perhaps under-report gas content by close to 30 percent. Gas-in-place estimates for coalbed methane resources may also have been under-estimated for paludal coals for the same reason.

- Mechanical problems following liner cementing were probably the result of a combination of factors. These included not running a liner top packer, and subsequent gas influx resulting in mud contaminated cement, as well as poor sweep during cement displacement, and an optimistic hole volume from a caliper survey that resulted in overstating cement requirements.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the efforts of the CER Site Manager, Mr. Bill Mathis, for his perseverance in getting this hole drilled to total depth. We also acknowledge the efforts of Mr. Frank Schuh for his original design of the bottomhole assemblies and for trouble shooting during drilling operations. This work was sponsored by the U.S. Department of Energy and was managed by Mr. Karl-Heinz Frohne at the Morgantown Energy Technology Center (METC).

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Table 1 Casing Program

	Hole Diameter, in.	Depth, ft	Casing, in.	Weight, lb/ft	Grade	Comments
Surface	17-1/2	115	13-3/8	54.5	K55	ST&C, 8RD
Intermediate	12-1/4	4,130	9-5/8	36.0	K55	LT&C, 8RD
Production	8-3/4	8,489	7	29.0	N80	LT&C, 8RD
Liner	6	8,200 - 9,466	4-1/2	13.5	N80	LT&C, 8RD

Table 2 Coal Bed Gas Content

Interval	Depth, ft	Core Type	Gas Content, SCF/ton
Mesaverde Coal	7,367 - 7,371	Conventional	543
Mesaverde Coal	7,371 - 7,380	Pressure*	765
Mesaverde Coal	7,571 - 7,579	Conventional	540

*BHT = 170°F; BHP (7,090 ft TVD) = 4,900 psi

Table 3 Observed Torque and Drag

	Hole Diameter, in.	Drill Pipe OD, in.	Depth, ft	Drilling Torque, ft-lbf	Drag, M lbs Up	Drag, M lbs Down
Below First Build	8-3/4	5.0	7,586	6,700	20	25
Tangent	8-3/4	5.0	8,362	14,100	60	40
Second Build	6	3.5	8,908	6,700	-	-
Cozzette	6	3.5	9,392	6,700	25	20

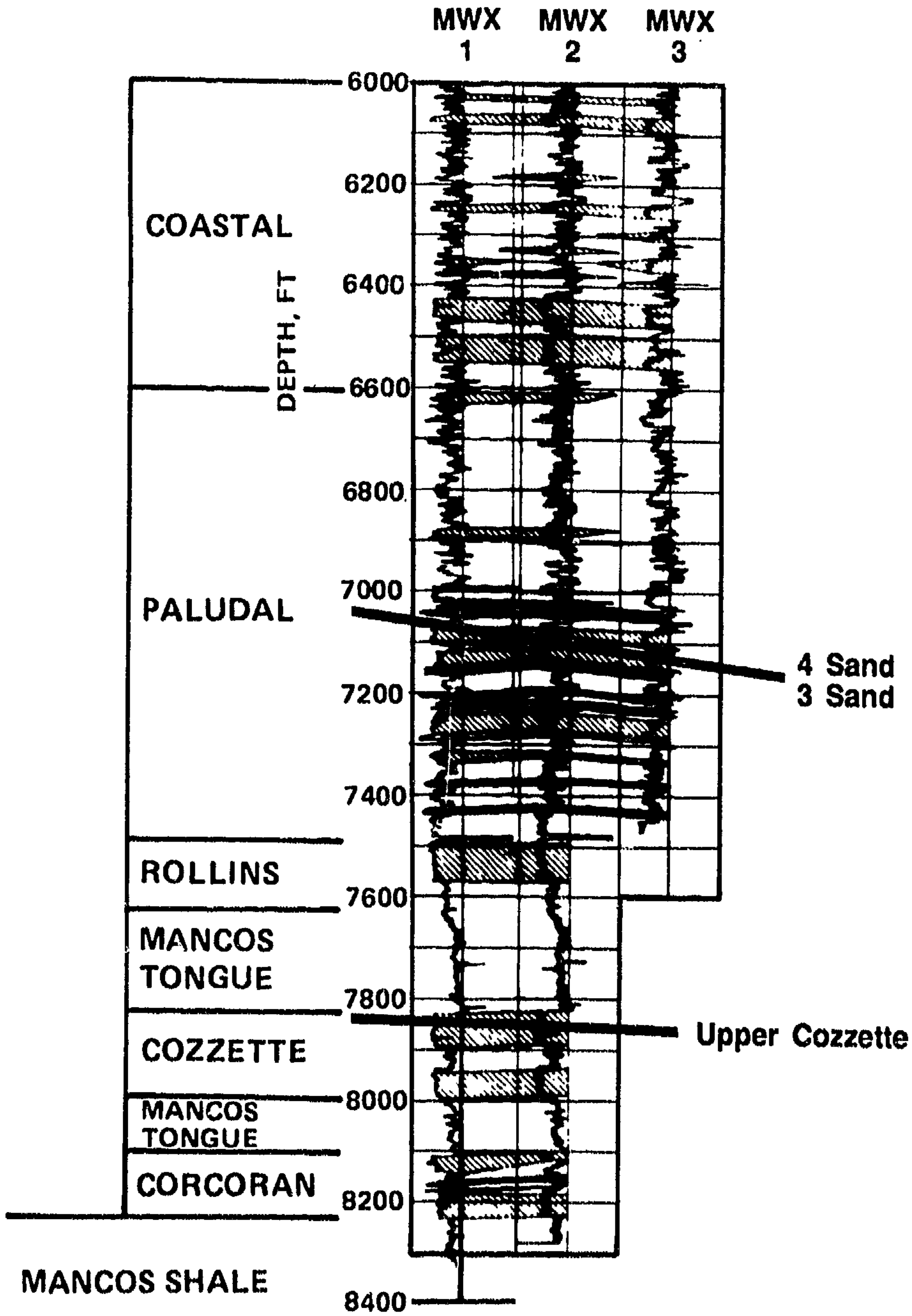

Figure 1 MWX Well Logs Across Paludal and Cozzette Reservoirs

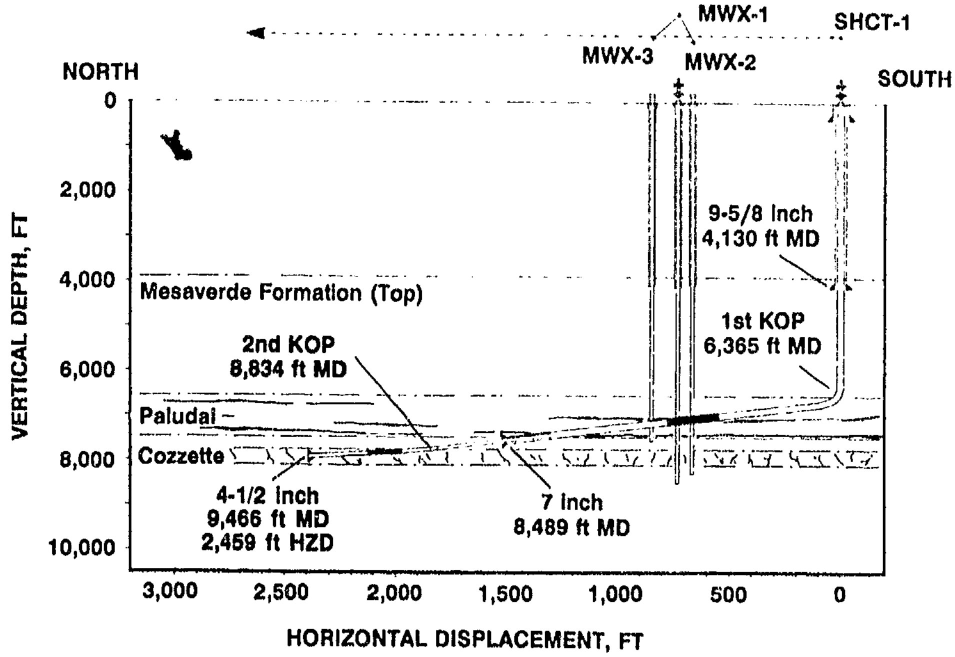

Figure 2 Slant Hole As-Built Profile

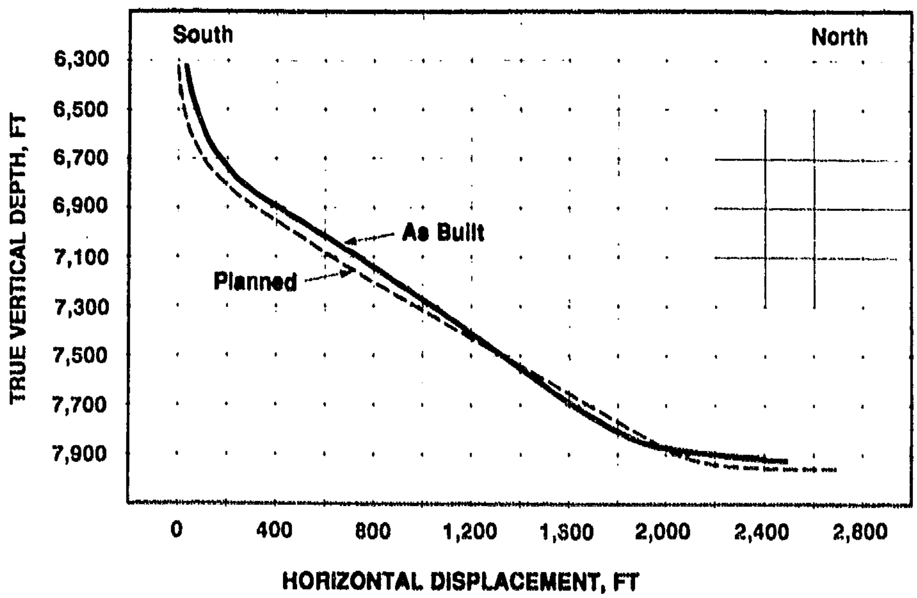

Figure 3 Slant Hole Completion Test Profile View

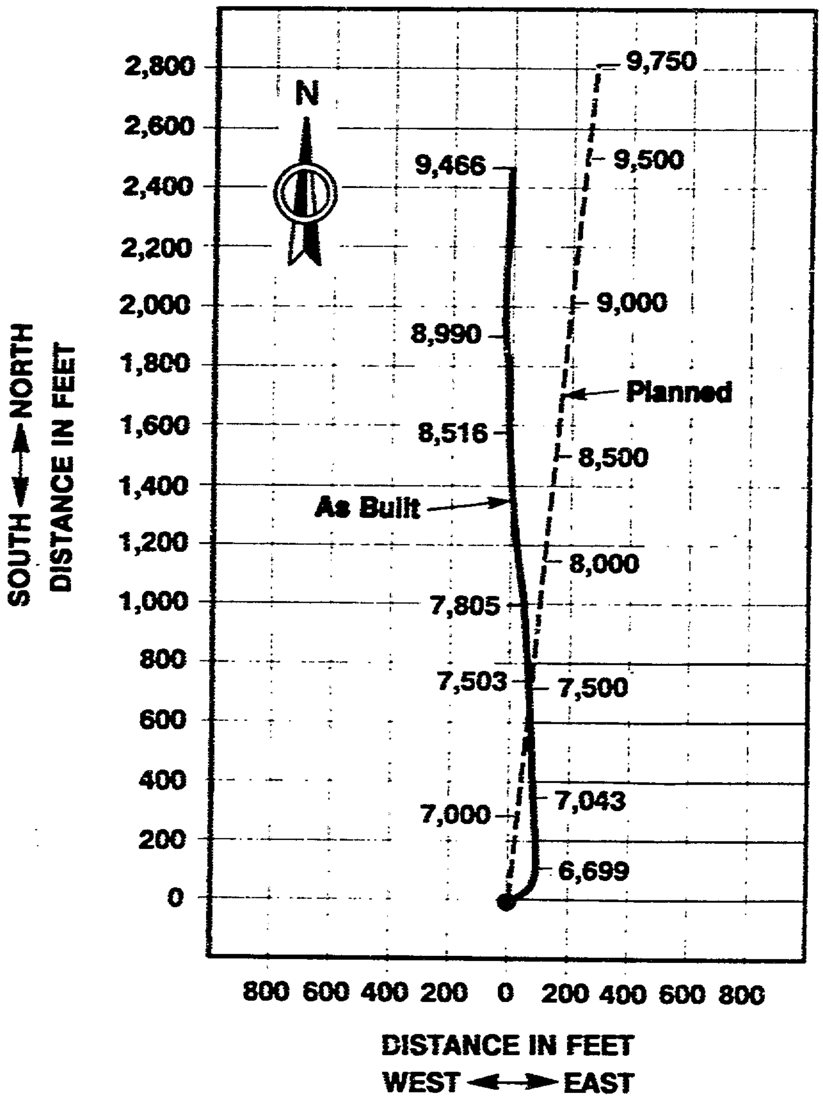

Figure 4 Slant Hole Completion Test Plan View

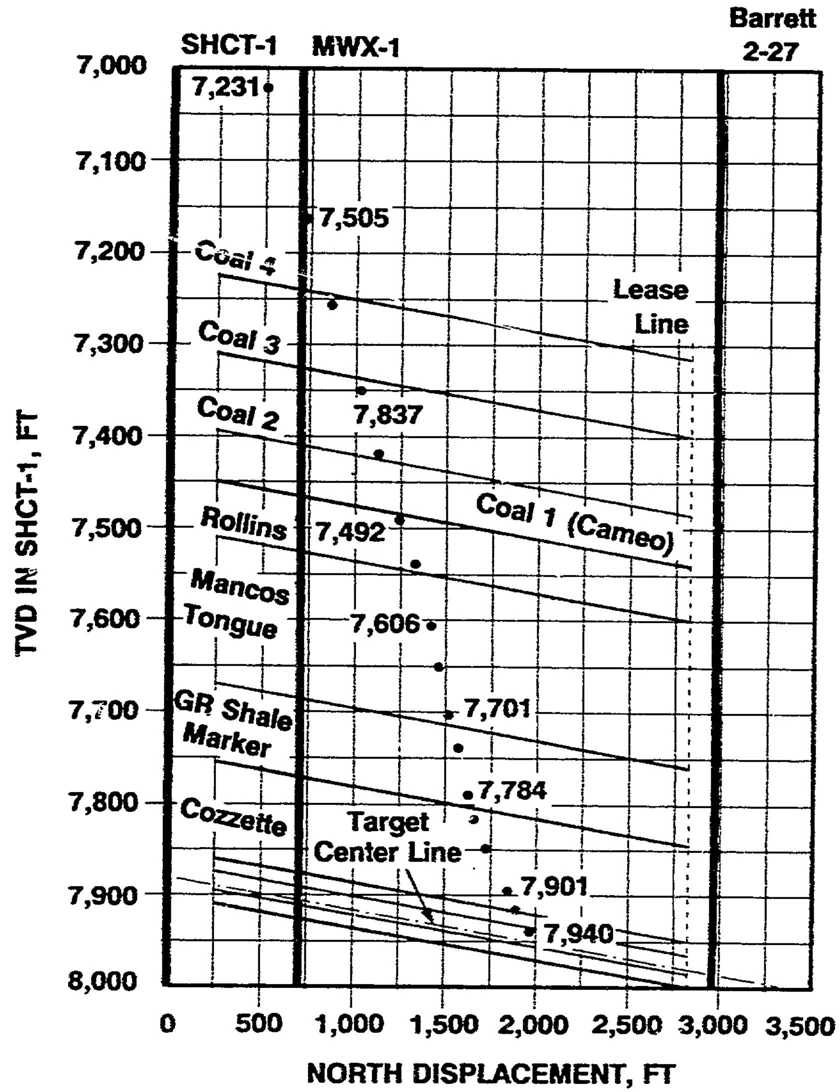

Figure 5 Wellbore Trajectory

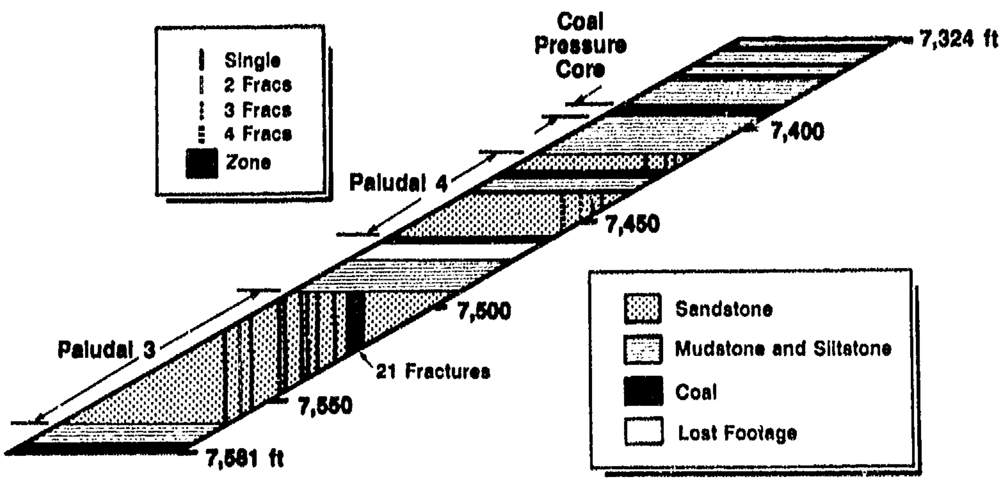

Figure 6 Natural Fractures in the Paludal Core Interval

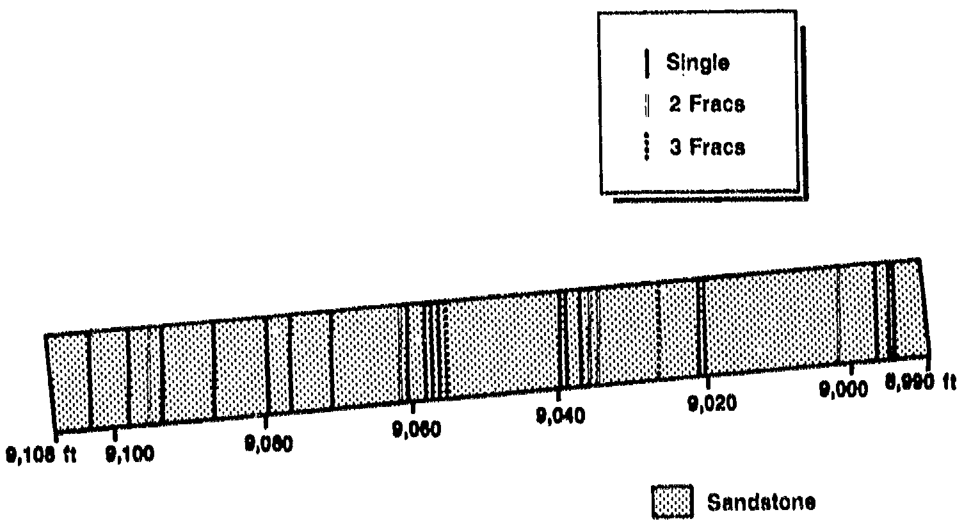

Figure 7 Natural Fractures in the Cozzette Core Interval

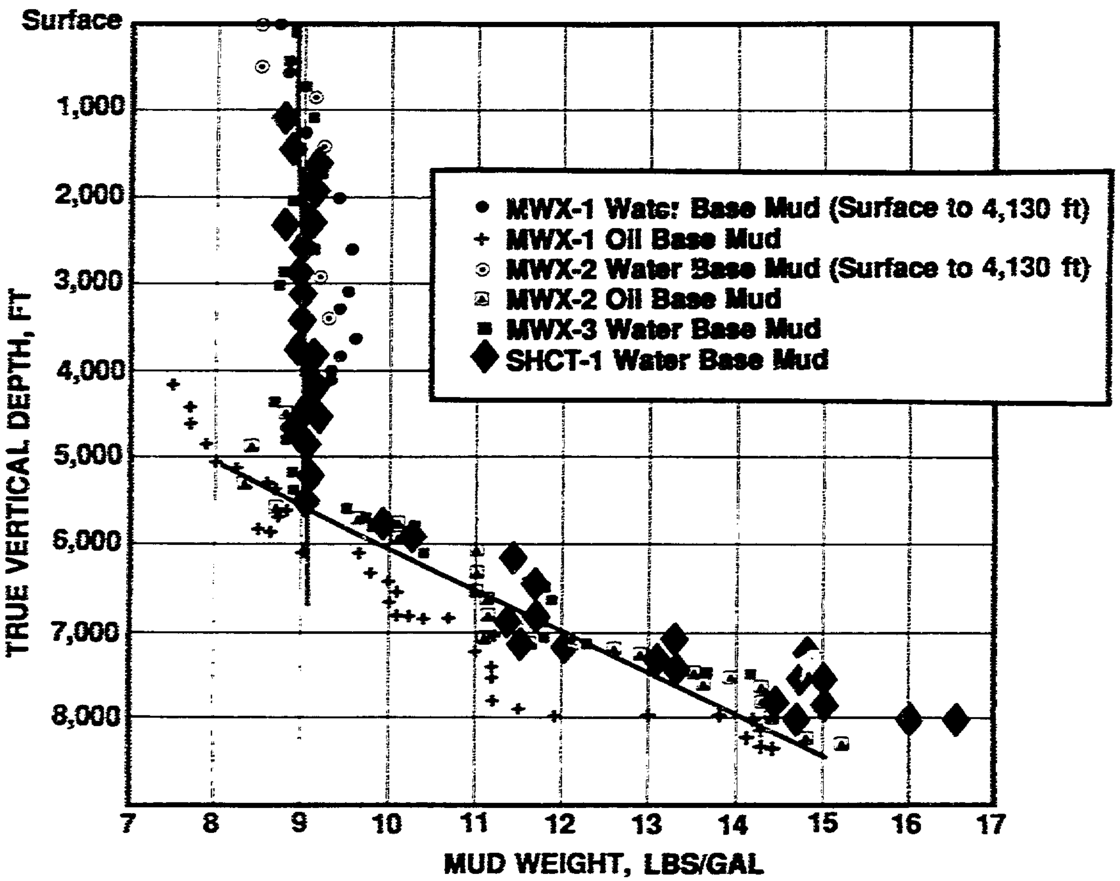

Figure 8 Mud Weight Comparison with MWX Wells